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COMPUTER MAPPING as an aid in AIR POLLUTION STUDIES

VOLUME TWO: INDIVIDUAL REPORTS

REPORT E
MONTREAL REGION STUDY

by

Jean-Maurice Granger

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16. Abstracts
A report of an individual case study of the Montreal Region is presented. The report is divided into two sections; comparing conventional and biological data for urban areas, and a monitoring technique based on epiphyte sensitivity. Also presented is an introduction discussing the theory and methodology and the mapping techniques. An appendix of a selected bibliography is included in addition to the appendix of computer graphics.

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COMPUTER MAPPING

as an aid in

AIR POLLUTION STUDIES

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PREFACE

From July 1, 1968 through December 31, 1969, the Laboratory for Computer Graphics and Spatial Analysis conducted a demonstration of several conceptual, methodological, and technical approaches to problems in the field of air pollution, employing computer-produced maps and allied displays. This work was done under a grant (No. 68A-2405D) from the Division of Control Agency Development, National Air Pollution Control Administration (NAPCA), Public Health Service, U. S. Department of Health, Education, and Welfare.

The results of this study, taken in its entirety, should make an important contribution to the work of Federal, state, and local air pollution agencies, especially in their efforts to determine the best control strategies for use in air quality control regions. The computer is an ideal tool for relating and combining sets of data, and for considering alternatives. For instance, graphic displays can contribute significantly to the evaluation of both short-term and long-term control strategies.

In demonstrating "the use of computer graphics as a means for more clearly portraying data related to the sources, distribution, and community effects of air pollution," the primary emphasis was on case studies for specific areas. The secondary emphasis, to support and complement the case studies, included:

(a) "the development of instructional manuals covering the procedures required for the preparation and interpretation of computer maps of various kinds, as related to air pollution,"

(b) "the use of certain newly developed techniques for describing, analyzing, and portraying quantitative surfaces and movements relative to such surfaces, as related to air pollution," and

(c) "an appraisal of alternative equipment, techniques, and computer programs presently or potentially available for the production of computer graphic displays pertinent to air pollution."

The case study regions were selected in consultation with NAPCA. Considerations included:

(a) sufficient air quality, emission, and related socio-economic and meteorological data--spatially distributed over the region--to enhance the likelihood of adequately demonstrating the mapping techniques;

(b) representative problems in data handling and mapping so that the techniques demonstrated would have applicability to as many other areas as possible;

(c) special problems in data handling and mapping so that as many techniques as possible could be adapted, developed, and tested;

(d) areas of which NAPCA and the individual investigators had special knowledge and could therefore utilize relevant research to enhance the study;

(e) areas where an immediate interest in mapping had been expressed for on-going Federal, state, and local air pollution activities.

Other research was undertaken to support and complement the case studies, and, in particular, to provide:

(a) the widest possible distribution of the mapping programs and accompanying explanation of the techniques through

i) copies of the Laboratory's SYMAP Computer mapping program,
ii) an introductory correspondence course in the SYMAP program,
iii) general program description and supplementary explanation for the existing user-manuals;

(b) a general review of present and potential hardware, output devices, and programs applicable to computer graphic displays of air pollution and related data;

(c) means for predicting, projecting, and correlating air pollution and related data, utilizing the latest

knowledge in planning, geography, and spatial analysis in general;

(d) dissemination of information on approaches and techniques to Federal, state, and local air pollution agencies, especially for use in the air quality control regions.

The final report is divided into two parts: Volume One: Summary, and Volume Two: Individual Reports--the detailed reports on the case study areas and the technical reports related to other research undertaken. The pertinent graphic displays are included with the appropriate individual report and a complete set is provided with the Summary Volume.

Introductory sections describing the air pollution and related data used are provided in the major case study reports for St. Louis and Kansas City; these should be referred to by anyone unfamiliar with the types of data and problems existing in this field. Detailed discussions of special data handling and mapping techniques are presented either as appendices to case study reports, or in separate technical reports.

The Summary Volume includes a discussion of all the areas of research undertaken and contains the complete table of contents for the reports of Volume Two. This should provide a useful reference of the special problems and technical discussions of one report which may be of interest to the reader of another detailed report.

The Montreal Region Study is presented here as Report E of Volume Two. It is divided into two sections -- comparing conventional and biological data, and a monitoring technique based on epiphyte sensitivity -- in addition to an introduction discussing the theory and methodology and the mapping techniques. An appendix of a selected bibliography is included in addition to the appendix of computer graphics.

The data used in this study was provided by Dr. Fabius Leblanc, S.C. Associate Professor in the Department of Biology at the University of Ottawa, and by the Service d'Urbanisme de la Ville de Montreal -- the City Planning Department of Montreal. In addition, Dr. Leblanc provided background papers and advice concerning his theories and methodology.

This study was under the direction of Jean-Maurice Granger, with the assistance of Steven Fosburg.

The report was principally prepared by Jean-Maurice Granger, with the assistance of Steven Fosburg and Gail Howrigan.

John C. Goodrich, Editor
Cambridge, Massachusetts
April, 1970

REPORT E
MONTREAL REGION STUDY

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1. INTRODUCTION

1.1 THEORY AND METHODOLOGY

This study is based on a theory and methodology developed by Dr. Fabius Leblanc of the University of Ottawa and other scientists, including J. De Sloover and D.N. Rao, with whom he has written articles pertaining to the pollution-indicator qualities of epiphytes. The epiphytes considered are essentially lichens and mosses, growing on trees. They possess two qualities that make them of special interest to the air pollution investigator: (i) their complete dependence on rainfall and ambient air for nutrients, and (ii) their enormous potential for accumulating toxic substances, even from highly diluted solutions.(1)

The theory posits a strong negative correlation between the concentration of air pollutants (or intensity of air pollution) and the fertility and degree of coverage of lichens and mosses found growing in the area.(2) It has been observed that as one approaches large urbanized areas or industrial complexes, epiphytes gradually decrease in vitality, coverage, and diversity of types, to such an extent that the central zones of these areas may be termed "epiphyte deserts."(3) Further, lichens and mosses may be ranked according to their tolerance of pollutants, although some are only differentially tolerant -- sensitive to one toxic substance but resistant or indifferent to another.(4)

1.1.1 Index of Atmospheric Purity

F. Leblanc and J. De Sloover proposed an Index of Atmospheric Purity (I.A.P.) -- an equation reflecting quantitatively the state of the epiphytes at a particular station. This Index is given as:

$$I.A.P. = \sum_{1}^{n} \left(\frac{Q \times f}{10}\right) \quad (5)$$

--n is the number of species present at a station.
--$\bar{Q}$ is the ecological index of each species, established by averaging the total number of epiphytes growing at the station in question with the totals from all other stations where that same species is present.
--f is the frequency coverage degree. Because it does not lend itself to precise numerical assignment, an arbitrary scale was devised: (6)

5 represented an epiphyte that was very frequent and had a high degree of coverage on most trees;
4 represented a species that was frequent or had a high degree of coverage;
3 represented a species that was infrequent or had a medium degree of coverage;
2 represented a species that was very infrequent or had a low degree of coverage; and,
1 represented a species that was very rare and had a very low degree of coverage.

They note that valid comparison is possible only for regions which are similar in climatological and ecological factors.

1.1.2 Application to Montreal Region

Dr. Leblanc applied the method to the Montreal region, with 349 sampling stations distributed nearly uniformly over the area. The area includes the islands of Montreal, Jesus, Perrot, and Bizard, along with a narrow band of territory south and east of the St. Lawrence River[7] and covers over 700 square miles.[8] Among the 1200 different species of lichens and mosses living in southern Quebec, 83 were selected by Dr. Leblanc as epiphyte indicators[9] for the Montreal region.

The main purpose of this Montreal Region Study was to define a technique for evaluating the pattern and intensity of urban air pollution on the basis of epiphyte sensitivity. To reduce the amount of time, effort, and money needed to gather the necessary information to do this, a trade-off was effected. This involved less accuracy in the description of the air pollution surface -- reducing the number of epiphytes measured and the number of points at which they are measured -- in return for greater ease in the gathering of data.

Regression analysis was used throughout the study. This is a technique for determining how much of the variation of one variable -- often the I.A.P. -- is attributable to another variable or variables -- such as the number of epiphytes. One of the measures produced by regression analysis -- R^2 -- was used frequently. R^2 is given in percent and is an indicator

of the degree of information retained. For example, an R^2 of 97% means that the data reduction resulted in a loss of 3% of the information contained in the original data. The total loss of information in all of these processes was not allowed to exceed 20%.[10]

1.2 MAPPING TECHNIQUES

1.2.1 Base Map Design

The SYMAP computer mapping technique requires first the detailing and preparation of a base map to provide the analyst with a visual evaluation of the geographical characteristics of the study area. A source map from the City Planning Department of the City of Montreal was used to develop the base map. Its scale (1/150,000) was blown up to 1/100,000, using the appropriate elective in the SYMAP program.[11] The data point coordinates were directly measured from Dr. Leblanc's points on the City Planning Department map.

The St. Lawrence and other rivers were specified by "white" or blank symbolism using the OTOLEGENDS package.[12] Outlines were shown with precision on the output map using blank point and line legends. The initial M[13] refers to the location of Mount Royal (municipal park), having an altitude of 760 feet. The size of the maps produced was 20 by 26 inches.[14] The frequency distribution of the data point values in each level -- between the contour intervals -- is given by the histogram displayed on the right hand side of the map.

1.2.2 Land Use Intensity Index

In conjunction with the base map, a crude "land use intensity index" was developed to provide background information on the level of urbanization. Land use in the Montreal area was classified into eight categories. As pollution is expected to vary with land use, the category numbers correspond to increasing pollution potential.

The locations of industrial activity were determined from Dr. Leblanc's source map, with the aid of a land-use map from the Planning Department of the city.[15] Two circles were selected, with radii of 5 and 10 miles from the city center.[16] The average population density in the inner circle is close to 35 persons per acre with a threshold of about 20 persons per acre. The density is only 5 persons per acre in the 5-to-10 mile ring with a threshold of 2 persons per acre 10 miles out from the city center.[17]

The nature of the land use (industrial, residential, or vacant) and the distance to the city center (0-5, 5-10, and 10+ mile radii) were determined for each of the 349 data points. Table 1-1 shows the index of land use intensity and the frequency distribution of the data points for the eight categories.

We see that about 12% (41) of the 349 values fall in the inner circle, 32% (111) in the 5-10 mile ring, and 56% (197) in the 10+ mile area. This is shown graphically in Figure E-1.

TABLE 1-1

LAND USE INTENSITY INDEX

index category	land use	distance from city center	number of data points
8	industrial	0-5 miles	17
7	residential	0-5 miles	24
6	industrial	5-10 miles	26
5	residential	5-10 miles	67
4	vacant	5-10 miles	18
3	industrial	10+ miles	22
2	residential	10+ miles	87
1	vacant	10+ miles	88

1.3 MONTREAL STUDY CONSIDERATIONS

1.3.1 Presentation of Data

In studying the I.A.P. values for the Montreal region, two separate zones were established -- the urban core and the rural areas surrounding it. To further facilitate the analysis, the data was mapped using two graphical procedures. The data values were grouped into eight contour levels in both cases, but the grouping itself was done differently in the two procedures. In the first, the total range of the data values was divided into eight equal intervals. (See Figure E-2.) Many of the data points fell in the most polluted category using this procedure. In the second procedure an equal number of data points were assigned to each contour interval. (See Figure E-3.) With this procedure a smaller portion of the study area was assigned to the most polluted category.

1.3.2 Correlation with Measured Air Quality Data

Although previous studies have correlated the I.A.P. with air pollution, no detailed statistical analysis has been performed to demonstrate the relation of I.A.P. to such particular pollutants as coefficient of haze (COH), sulfur dioxide (SO_2), and insoluble residue (RES). Determining the relationship of the I.A.P. either to individual pollutants or to certain combinations of these pollutants is of considerable interest. Unfortunately, the number of sampling stations at which these pollutants are observed in

Montreal and the portion of the study area they cover are quite small. Moreover, for the data available, the I.A.P. -- an indicator which changes relatively slowly -- varied little over the region for which values of COH, SO_2, and RES are observed. It was, therefore, not possible to evaluate the results of the statistical analysis in this study.

2. COMPARING CONVENTIONAL AND BIOLOGICAL DATA

2.1 DISPLAYING BIOLOGICAL VALUES FOR THE URBAN REGION

2.1.1 The Index of Atmospheric Purity

Figure E-2 shows the I.A.P. for an equal value range from 0 to 138.9, distributed into eight levels. Over one-third of the 349 data point values (119) fell into the most-polluted category -- corresponding to the lowest I.A.P. Another third were in the next two categories (58 and 60) and the last third were distributed into the remaining categories as follows: 43, 40, 24, 4, and 1.[18]

Figure E-3 shows the I.A.P. for an equal distribution of data points. This mode of distribution corresponds to an unequal value range interval, with the same number of data point values being expected to fall into each category. The distribution was: 20, 67, 44, 43, 44, 44, 43, 44.[19] The degree of air pollution concentration is more clearly perceived in the urban area, even with the two unbalanced categories.

Regression analysis was performed to see if the land use measure and the I.A.P. were significantly related. In some ways this is a minimal test of the relationship, since the land use intensity index was chosen to correspond to pollution. The analysis resulted in an R^2 of 80.9%, a significantly high level.

2.1.2 The Level of Air Pollution

The objective of this set of maps was to test visually one of the variables entered into the computation of the I.A.P. -- the simple number of epiphytes present at each station. This number ranged from 1 to 32, representing the different species. The ecological index and the degree of coverage by species were disregarded in this analysis.

Figure E-4 shows the level of air pollution for an equal value range distribution from 0 to 32. The allocation of data points into eight categories, starting with the most polluted level, was: 81, 46, 45, 64, 53, 45, 10, and 5.[20] When the level of air pollution was mapped according to an equal distribution of data, the significant number of similar values caused an uneven distribution of data points and hence an unacceptable example.[21]

Regression analysis was used to relate the I.A.P. and the number of epiphytes per station. For the entire region (349 values) the R^2 was found to be 97% and the multiple R, 0.99. This regression shows that 97% of the variation in the total I.A.P. can be explained by the variation in the simple number of epiphytes present at each station.

The land-use intensity index and the number of epiphytes per station were also correlated. The resulting R^2 was 87%. Even though the relationship of the I.A.P. to the number of epiphytes produced a cor-

relation six percent stronger than that of the land-use index and the number of epiphytes, the difference does not appear to be significant, due to imprecisions in land-use measurements. The points at which the epiphyte measurements were taken correlate indeed with the land-use, but not necessarily at the local level.

2.1.3 I.A.P. in the Urban Core

The Montreal region was divided into two areas for this study -- the "rural" part and the "urban" part[22] -- with the boundary line approximately 10 miles from the city center. The objective of the following maps was to focus on the biological data for the urbanized part of the Montreal area so that comparisons could be made with the conventional data. Only five categories of land use were considered for the urban area.[23]

Figure E-5 shows the I.A.P. over the urbanized area of Montreal for an equal value range distribution. The most polluted of the five categories contained 123 values (more than one-third of the total number of data point values, and over six-sevenths of the 142 urban values). The remaining categories had only 16, 2, 1, and 0. Broadly speaking, the urban area corresponds to the limit of the area of "maximum" air pollution concentration, according to epiphyte sensitivity. If the simple number of epiphytes had been used as a proxy variable for the I.A.P., the distribution of the 142 urban values into 5 categories would have been: 109, 25, 6, 1, and 1. This distribution is reasonably close to the one for an equal value range.

Figure E-6 shows the I.A.P. for an equal distribution of data point values. Although an even distribution was not achieved, a better appraisal of the spatial tendencies was possible, as the values were: 19, 38, 28, 29, and 28.[24] Two regression analyses were performed to test the number of epiphytes against the I.A.P. separately for the rural and urban areas. The results were:

urban area (142 values): R^2 = 96% (multiple R of .98)
rural area (207 values): R^2 = 98% (multiple R of .99)

The R^2 was slightly less in the urban portion, but the difference was not significant.

2.2 DISPLAYING CONVENTIONAL VALUES FOR THE URBAN REGION

The conventional data provided by the City of Montreal Department of Health dealt with three kinds of measurements: coefficient of haze (COH), sulfur dioxide (SO_2), and insoluble particulates (RES). The intended comparison (visual as well as statistical) between the biological and conventional data was hindered due to the very limited area covered by the three series of data. They dealt only with the central core of the urban area.[25]

The objective of the following maps was to portray as accurately as possible the spatial distribution of the conventional data, by type of measurement. They used the "D-Barriers"[26] option, limiting the interpolated surface to the 10-mile radius which approximates the urban area. The south shore of the river was eliminated, since there were no data point values for that area.

2.2.1 Concentration of COH

Figure E-7 shows the concentration of COH for the city of Montreal. The averages for 1968 were known for 12 sampling stations. The distribution into four categories -- from most to least polluted -- was 4, 2, 3, and 3.

In comparing the COH values with the I.A.P. values, only 9 data points were found to have sufficient spatial fit to be considered. The data series was much too small to offer meaningful statistical testing. The lack of relationship -- R^2 of 10% -- is not surprising in view of the fact that the I.A.P. is a long-term variable, while COH is not. Lichens and mosses need time (at least 3 to 4 months) to reflect increases in the level of air pollution and years to recover. Thus, their state at any time may reflect a previous air pollution incident, or, alternatively, may not yet have "caught up" with the present state of air pollution. Although expected for statistical reasons, the R^2 found was deceptively low.

2.2.2 Concentration of SO_2

Figure E-8 shows the concentration of SO_2 for the city of Montreal. The 12 stations measuring SO_2 were generally located differently from those measuring COH. The distribution into four categories was even in this case.

Only 10 of the values had a good spatial fit with the I.A.P. locations. The test was still meaningless

as it produced an R^2 of 9%. The failure of this test, as of the previous one, can be explained by the fact that the City's air pollution measurements were conducted entirely within the core area, and thus did not provide rural values needed for a meaningful comparison with the I.A.P. series.

2.2.3 Concentration of RES

Figure E-9 shows the concentration of RES for the city of Montreal. Fifteen values were distributed into 4 categories: 4, 4, 3, and 4. Only 13 of the 15 available values were used for reasons of spatial fit, and they showed an R^2 of 7%.(27)

2.3 DISCUSSION OF COMPARISON PROCEDURES

Some common trends have been revealed between the biological and more conventional indicators. However, there are some evident discrepancies and weaknesses in the corresponding series. The main weakness is due to the spatial and historical limitations on the Montreal sampling network, and the shortness of the series (12 or 15 values) which have been recorded. A broad extension of the sampling network over the entire Montreal region is needed, as well as time series extending beyond one-year averages.

Using only three types of measurements presents severe limitations. To permit a more detailed correlation with the biological indicators other variables are needed. These might include the diversity of all chemi-

cal and natural pollutants, the humidity and heat of the urban island, the direction and frequency of the dominant winds, and exposure to the sun. For biological indicators, a factor analysis might take into account the altitude as well as esposure to the sun and height over the watertable, etc. The biological indicators -- through the I.A.P. -- reflect the long-range effects of air pollution, but a time-lag does exist between the emission of new pollutants and an observable change in texture, color, or coverage, in the epiphyte populations.

Because of all these discrepancies as well as the differing nature and characteristics of the corresponding series, more information is needed before any meaningful evaluation can be carried out. The following section elaborates on a simplified I.A.P. technique which shows amazing potential for portraying the air pollution level of an urban area in the absence of more sophisticated monitoring systems.

3. A MONITORING TECHNIQUE BASED ON EPIPHYTE SENSITIVITY

The objective of this section is essentially operational. We have already shown that the variation in the I.A.P. is almost completely explained by the variation in the number of epiphytes (R^2 = 97%). Thus, little information is lost by using the epiphyte counts to measure pollution instead of the more complex and therefore more expensive I.A.P. In this section, we show that even reduction to a small number of different epiphytes results in little loss of explanatory power.

The steps in the monitoring technique based on epiphyte sensitivity are summarized as follows:

(i) selecting a relevant set of epiphytes using a reduced amount of information;

(ii) optimizing the number of sampling stations for the Montreal area; and

(iii) undertaking complementary research.

3.1 SELECTING THE MOST RELEVANT SET OF EPIPHYTES

3.1.1 The "Best" Epiphyte Selection

Regression analysis was again used to select as many as eight variables from Dr. Leblanc's intuitive selection of 16. Recording a species by its identity is less time-consuming than the recording of both its identity and the degree of coverage associated with it. Accordingly, the index was determined so as to vary only by species, in a range from 0 to 5.[28] Certain epiphytes display some fertility characteristics useful for the evaluation of air pollution thresholds. Different weights were, therefore, given to the fertility factor of the "fertile" species. This factor was then combined with the previous two -- presence and coverage -- to produce an "aggregated" index.[29]

Finding the best selection thus consists of selecting the highest R^2 for the first variables entered in the stepwise regression equation. The epiphytes for this selection are shown in Table 3-1, in descending order of explanatory power.

TABLE 3-1

BEST SELECTION (BS) EPIPHYTES

(1) Physcia Millegrana	(5) Parmelia Subaurifera
(2) Physcia Stellaris	(6) Candelaria Cancolor
(3) Xanthoria Fallax	(7) Parmelia Sulcata
(4) Leskea Polycarpa	(8) Lecanora Subfuscata

TABLE 3-2

BEST SELECTION - TOTAL AREA

Step 1: (1) Physcia Millegrana, coefficient of 134.506

Step 2: (1) 84.987 + (2) 75.889

Step 3: (1) 68.933 + (2) 56.623 + (3) 41.418

Step 4: (1) 47.861 + (2) 46.667 + (3) 43.036 + (4) 44.431

TABLE 3-3

BEST SELECTION - RURAL VERSUS URBAN

Rural

Step 1: (1) 136.824

Step 2: (1) 83.033 + (2) 78.840

Step 3: (1) 65.884 + (2) 58.538 + (3) 44.056

Step 4: (1) 64.713 + (2) 57.521 + (3) 53.476 + (5) 44.397

Urban

Step 1: (1) 109.506

Step 2: (4) 67.818 + (1) 75.215

Step 3: (4) 66.246 + (1) 57.281 + (2) 56.504

Step 4: (9) 92.924 + (4) 51.108 + (1) 58.401 + (2) 51.017

For the entire area and all data points, the "Best Selection" of eight had an R^2 of 97.1% (for a multiple R of 0.985). When only the best four variables were considered, the R^2 was 95.5% (for a multiple R of 0.977).(30) When the two zones were considered separately, the results were:

rural:	8 variables--R^2	=	97.5%	for a multiple R of	0.988
	4 "		96.1%	"	0.980
urban:	8 "		95.4%	"	0.977
	4 "		90.9%	"	0.954

Figure E-10 shows the spatial distribution of the first variable in Table 3-1. The explanatory power of this variable, Physcia Millegrana, exhibits an R^2 of 89.4%. Because the spatial distribution is not completely satisfactory it is difficult to rely on one single species, despite a high enough explanatory power.

Entering progressively the four most relevant variables -- taking into account the fertility factor -- increases both the level of explanation and the spatial distribution of the selection. The coefficients vary along with the enlarging regression equations. Table 3-2 shows this stepwise entering of variables. The numbers in brackets refer to the epiphytes in Table 3-1.

Figure E-11 shows the results of step 4, or the Best Selection of four variables by coverage and fertility. Figure E-12 is the spatial display of the residuals between the I.A.P. and the Best Selection of four species. The difference in the residuals as shown in Figure E-12 shifts from positive to negative (and vice-versa) approxi-

mately on the outskirts of the urban area. Consequently, the regression analysis was carried out separately for the two areas, offering two complementary "best" selections: rural versus urban. These are shown in Table 3-3.

When we compare the three sets of four variables in Tables 3-2 and 3-3 it is apparent that both the urban and rural sets have three common variables with the total set; the composition, however, is very different:

Total -- (1) + (2) + (3) + (4)
Rural -- (1) + (2) + (3) + (5)
Urban -- (9) + (4) + (1) + (2)

3.1.2 The "Alternate" Epiphyte Selection

In the alternate selection series, the coverage index remains 0 to 5, but the fertility index of the 7 variables sensitive to it is not taken into account. Table 3-4 shows the epiphytes for this selection in descending order of explanatory power.

Directly following the highest R^2 for the entire area was the "alternate selection," with an R^2 of 97.1% (multiple R of 0.985) for eight variables. This is the same as for the best selection. For four variables the R^2 is 94.6% (for a multiple R of 0.974). This is o.5% less than the corresponding R^2 for the best selection. When the area was divided into urban and rural zones the results were:

rural:	8	variables--R^2 =	97.4%	for a multiple R of	0.987
	4	"	95.7%	"	0.978
urban:	8	"	94.6%	"	0.973
	4	"	91.4%	"	0.956

TABLE 3-4

ALTERNATE SELECTION (AS) EPIPHYTES

(1) Physcia Millegrana
(2) Physcia Adcendens
(3) Parmelia Subaurifera
(4) Xanthoria Fallax
(5) Leskea Polycarpa
(6) Candelaria Cancolor
(7) Lecanora Subfuscata
(8) Parmelia Sulcata

TABLE 3-5

ALTERNATE SELECTION - TOTAL AREA

Step 1: (1) Physcia Millegrana, coefficient 150.570
Step 2: (2) 94.655 + (1) 94.097
Step 3: (3) 83.061 + (2) 87.039 + (1) 83.293
Step 4: (3) 81.422 + (2) 63.946 + (1) 64.391 + (4) 44.972

TABLE 3-6

ALTERNATE SELECTION - RURAL VERSUS URBAN

Rural

Step 1: (1) 154.769
Step 2: (1) 95.616 + (2) 97.584
Step 3: (1) 84.624 + (2) 90.992 + (3) 75.089
Step 4: (1) 64.783 + (2) 66.333 (3) 74.856 + (4) 46.256

Urban

Step 1: (1) 112.756
Step 2: (9) 169.549 + (1) 97.901
Step 3: (9) 165.561 + (8) 46.802 + (1) 72.940
Step 4: (9) 137.457 + (8) 51.245 + (1) 51.099 + (4) 39.398

These results are close to those found for the best selection. Given the difficulty of observing the fertility of a given species, the alternate selection proves to be preferable from an operational viewpoint.

Table 3-5 shows the progressive entering of the alternate selection variables in the regression equation. The explanatory power of the first variable entered exhibits an R^2 of 88.4%. Figure E-13 shows the results of step 4, or the alternate selection of four variables by coverage only. Figure E-14 is the spatial display of the residuals between the I.A.P. and the Alternate Selection of four species. It may be noted, again, that the difference shifts from positive to negative on the approximate outskirts of the urban area, thus indicating the possibility of a better selection by separately examining the urban and rural areas. This is shown in Table 3-6.

The rural selection is composed of the same four epiphytes as is the total one, and in the same descending order. The urban one, however, is somewhat different in that it only retains two variables from the total selection: (9) + (8) + (1) + (4).

3.1.3 Comparison of Selections

Given the relative simplicity of directly observing and recording only the identity and the coverage of four species -- and the high explanatory power retained -- the alternate selection is preferred on operational grounds. The alternate selection of 4 species explains 94.9% of the total I.A.P. This R^2 breaks down into an urban R^2 of 91.4% and a rural one of 95.7%.

3.2 OPTIMUM NUMBER OF SAMPLING STATIONS

The optimum number of stations per zone was estimated for the alternate selection-step 4 urban epiphytes in the urban zone, and the alternate selection-step 4 rural epiphytes in the rural one. The level of explanation was to be kept at an acceptable minimum of 80.0% (R^2).

3.2.1 Technique and Assumptions

We started with the distribution of the I.A.P. over the entire area (about 1,000 square miles), and the 349 sampling stations. It was assumed (until further study) that the I.A.P. evaluated by Dr. Leblanc on the basis of epiphyte sensitivity represents the correct level of atmospheric purity, or conversely, the intensity of air pollution.

The level of explanation previously reached consisted of a "double approximation": in choosing the alternate selection only coverage was considered, and then only coverage for four variables. This gave us an R^2 of 94.9% for the total area, 95.7% in the rural zone, and 91.4% in the urban one. By using a simple ratio we find that to achieve the desired R^2 of 80% or higher, the smaller number of sampling stations should therefore explain at least 83.6% of the I.A.P. defined over the present 349 stations in the rural zone, 87.5% in the urban zone, and 84.3% for the total area.(31)

3.2.2 Application and Findings

We obtained for the total area 297 data points instead of 349, for the rural one, 173 points versus 207, and for the urban one, 124 instead of 142.(32)

take into account the accuracy of the geographical distribution of air pollution concentration. The reduced number of sampling stations were selected here at random, from Dr. Leblanc's original sampling "network."

Figure E-15 displays in a composite form both urban and rural alternate selection-step 4 epiphytes, the data being distributed into eight categories to allow a visual comparison with the I.A.P. distribution of Figure E-2. This twin distribution averages only an R^2 of 80%, despite the closeness of the spatial fit.

3.3 SUMMARY OF FINDINGS

The proposed I.A.P. technique can now be briefly stated: let us first cover an urban region with a differentially spaced grid -- a 2-mile spacing over the whole region, and a 1-mile spacing over the urban area. This urban area is defined by a population density threshold of about 20 persons per acre. The land use pattern will indicate when to use the 2 or 1-mile spacing in this urban zone: when industrial, narrow spacing; and when residential or vacant, large spacing.[33]

We assume that the appropriate selections of four representative epiphytes are known,[34] and the coverage has been recorded along with the presence in a survey. Hopefully the data is recorded within each grid cell (one value per cell) and the air pollution intensity displayed by the interpolated surface of the SYMAP program.

3.3.1 Guidelines for Future Research

Testing the biological indicators in the Montreal area should prove statistically more significant, undoubtedly, with many more conventional measurements of pollution variables. A factor analysis could be carried out to offer a better appraisal of the impact of some physical characteristics of the region (on the vitality of the epiphytes, altitude, humidity, exposure, and height over the watertable). A comparative analysis between two regions may prove significant and enlightening.

Selecting America-wide species (or species common to a continental region) may prove an interesting shortcut. The regression coefficients could be determined by region, and recorded in a general table. This would permit a rough calculation of the level of air pollution in the urban regions where a conventional sampling network is not yet operative.

An urban model for air pollution evaluation with biological indicators may be designed to portray the situation in a city. One may rely mainly on a narrow strip having relatively intensive sampling along the direction of the dominant winds, with sparse sampling over the rest of the area under consideration. Some "artificial ecological settings" may also be devised using a selection of most significant species, to be used in cities where trees are barely present. Needless to say, they can hardly replace a comprehensive monitoring network in a conventional way.

The epiphytes have an intrinsic characteristic of displaying a high degree of sensitivity to the air pollution level in toto, without giving a clear indication of the most detrimental pollutant.[35] This offers an interesting political consideration. No strong local lobbying is to be expected from businesses that pollute, since no single pollutant is identified. This I.A.P. technique could be used well for American cities to preselect the most relevant cities where selective federal funds could supplement local efforts.

3.3.2 Outline of Findings

(i) The mere presence or absence of the species explains as much as 97% (R^2) of the global I.A.P.

(ii) A twin selection of four species (recorded by presence and coverage only) offers in the urban area an R^2 of 91.4%, and 95.7% in the rural one.

(iii) The appropriate spread of the two selections -- explaining at least 80% of the I.A.P. -- fits a grid with a spacing of 1 mile in the urban area, and 2 miles over the rural one.

(iv) About six-sevenths of the "urban" values fall into the most polluted category, assuming an equal value range over eight categories. This occurs for an urban density threshold of about twenty persons per acre.

(v) The general findings are combined into a simple and feasible I.A.P. technique derived from Dr. Leblanc's theoretical methodology and experiments for the Montreal urban region.

REFERENCES

(1) De Sloover and Leblanc, "Mapping of Atmospheric Pollution on the Basis of Lichen Sensitivity," p. 3.

(2) See F. Leblanc, "Epiphytes and Air Pollution," in "Air Pollution: Proceedings of the First European Congress on the Influence of Air Pollution on Plants and Animals," Wageningen, 1968.

(3) De Sloover and Leblanc, op. cit., p. 3.

(4) Ibid., p. 1.

(5) De Sloover and Leblanc, "Apparent Effect of Air Pollution on the Distribution and Grwoth of Lichens and Mosses in Montreal," p. 9. The only reason for dividing the sum (Q x f) by 10 is to provide a smaller and more manageable figure.

(6) Ibid., p. 8.

(7) Ibid., p. 4.

(8) The study area to be considered was defined by a line connecting the most remote stations (plus an additional 2-mile-wide zone). The area shown in the computer maps comprises almost 1,000 square miles, 200 of which are included under the term "urban" (defined by a circle with a 10-mile radius about the center of the city; the periphery of the circle corresponds to an average population density of approximately 2 persons/acre). When the bodies of water (160 square miles) are subtracted out, the study area contains 160 square miles of urban area and 680 square miles of rural area.

(9) Among them, a more relevant set of 16 will be examined later in the report.

(10) This was chosen as an "acceptable" loss. There is, of course, nothing magical about this figure of 20%. A similar analysis could have been carried out so that only 10% -- or any other reasonable figure -- of the information was discarded.

(11) Elective 13 of the SYMAP program changes the scale of the map. See Volume Two, Report K for a discussion of the various electives.

(12) A standard package of the SYMAP program; see Volume Two, Report K. Version V of SYMAP on the IBM 7094 was used for this project.

(13) Row 87, column 152 of the output map.

(14) 159 rows by 259 columns.

(15) Service d'Urbanisme de Montreal, Bulletin Technique no. 5, "Urbanization," 1964, Map no. 2.

(16) The city's center is given by the intersection of Craig and McGill Streets (Source: same as above).

(17) Service d'Urbanisme de Montreal, Bulletin Technique no. 1, "La Vague d'Expression Metropolitaine," 1964, Map no. 2, and Chart no. 3.

(18) If the range of values is contracted to the interval between the extreme values 1 to 138.9, the distribution in eight categories then becomes 122; 57 and 59; 43, 39, 24, 4, and 1. This is still extremely close to the previous one.

(19) The computer was unable to allocate the values to their proper categories because of the rounding procedure.

(20) If the value range had been restricted to the interval 1 to 32, the distribution would have been: 93, 40, 51, 66, 48, 40, 8, and 3. The difference is quite significant in this case.

(21) The distribution was: 0, 81, 46, 45, 24, 65, 37, and 51.

(22) Of the 349 data points, 207 were rural and 142 urban.

(23) Of the 142 urban sampling stations, 134 were in land-use categories 8 to 5. Only 8 out of 18 values from category 4 were considered urban. This is because the most peripheral vacant land was left out, and only the isolated vacant land values were kept in.

(24) The symbolism was delimited here by black contour lines. Note that relying on the number of epiphytes instead of the I.A.P. would be of no help in this case; the distribution was 0, 43, 40, 31, and 28.

(25) The location of the sampling stations solely within the municipal boundaries of the city of Montreal was one of the constraints.

(26) A package of the SYMAP program. See Volume Two, Reports K and L for discussions of the use of this option.

(27) Further statistical analysis was conducted -- on an extremely weak basis. Given the sizes of the three series (COH, SO_2, and RES), and the need for enlarged statistical bases, we extended the 12, 12, and 15 corresponding figures to three series of 24 (all having the same locations). This was done by carefully considering their spatial variations, the land use context, and so on. I.A.P. values corresponding to 20 of the 24 previous locations were retained; 4 more were estimated to make the two sets of data spatially complete. With I.A.P. as the dependent variable (the constant in the regression equation being kept equal to 0), the COH regression coefficient was found to be +0.40, the RES coefficient -0.05. SO_2 was rejected by the F test. The R^2 remained poor (48%). Statistically, this attempt to relate all of these variables was inconclusive.

(28) 0 was used when a species was not found present.

(29) Sixteen species were ranked from 0 to 5 when fertility was not being considered. 7 of them showed a fertility characteristic; this was arbitrarily weighted in different tests as 1, 2, 3, 4, and 5, leading to different scales of 0 to 6, 7, 8, 9, and 10, when combined with the basic coverage index from 0 to 5. The highest explanatory power found corresponds to the weight of 1: defining a Best Selection for 9 species ranking 0 to 5, and 7 ranking 0 to 6. The Alternate Selection later defined used all 16 species at the basic 0 to 5 "coverage" scale.

(30) One may note that this simplification led to the same R^2 of 97% (when correlated with the I.A.P.) as the plain number of species over all 349 stations, disregarding all other variables.

(31) A simple ratio is calculated here. For the total area 100% corresponds to the I.A.P. for 349 stations, and an R^2 of 94.9% corresponds to the alternate selection of four epiphytes over the same 349 stations. An R^2 of 84.3% of the same alternate selection of four epiphytes corresponds to some reduced number of sampling stations over the same area. It can be seen that the combined R^2 of 80% is the product of the two: 94.9% x 84.3%. This resulting R^2 breaks down into an R^2 of 83.6% over the rural area, and 87.5% over the urban one.

(32) Spatially, for the total area this gives one data point for every 2.8 square miles, instead of one for every 2.4 miles; for the rural area, one for every 4.0 square miles versus 3.3; and, for the urban, one for every 1.3 square miles versus 1.1.

(33) The 1-mile urban spacing is accepted as the safe side of our previous finding of 1.3 square miles per urban station corresponding to the minimum R^2 defined (80% of total I.A.P.).

(34) An analysis will have to be carried out in each study area to determine the best four epiphytes to use. There is little difficulty if the area under study is in a similar ecological setting, as in Southern Quebec.

(35) Further laboratory experiments may give more precise results, as shown by Dr. Leblanc.

APPENDIX ONE

COMPUTER GRAPHICS

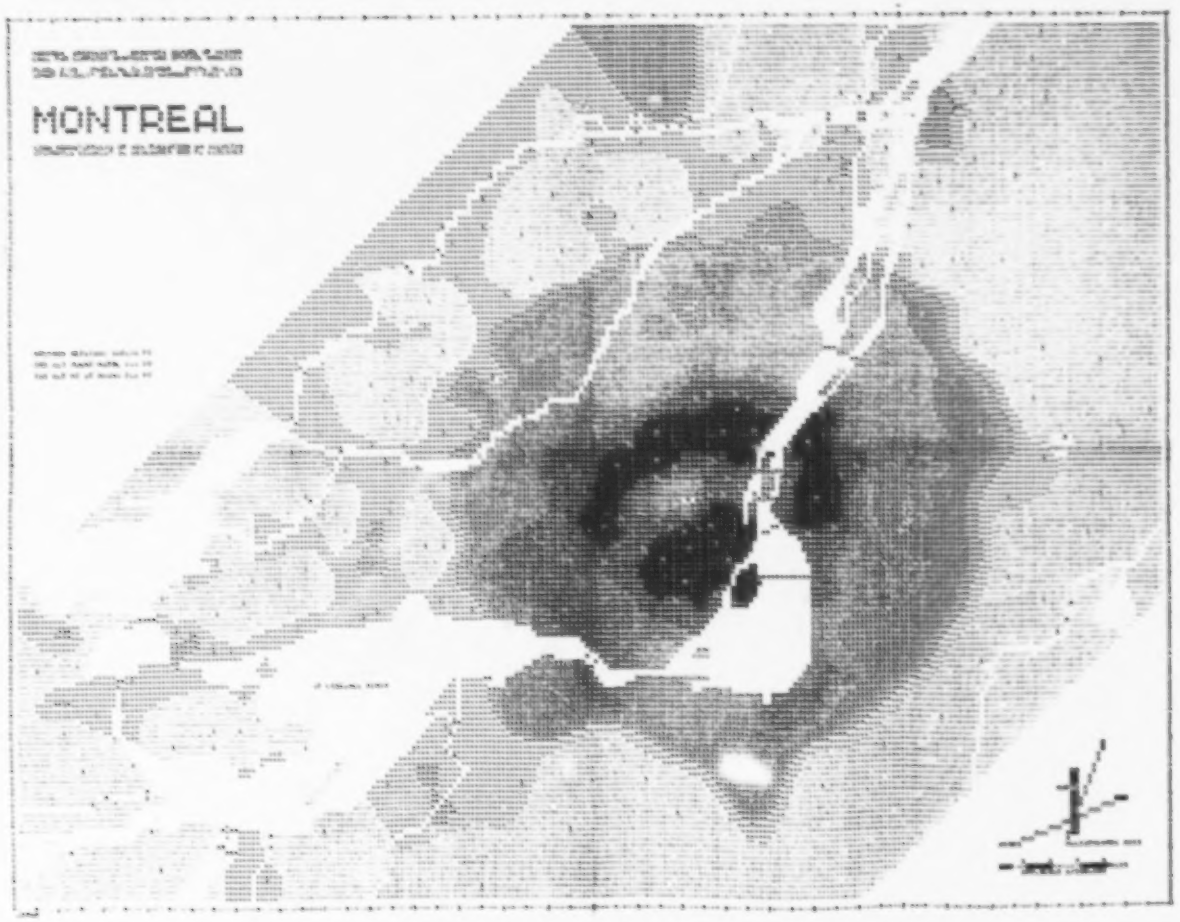

FIGURE E-1

MONTREAL REGION STUDY
Distribution of Land Use

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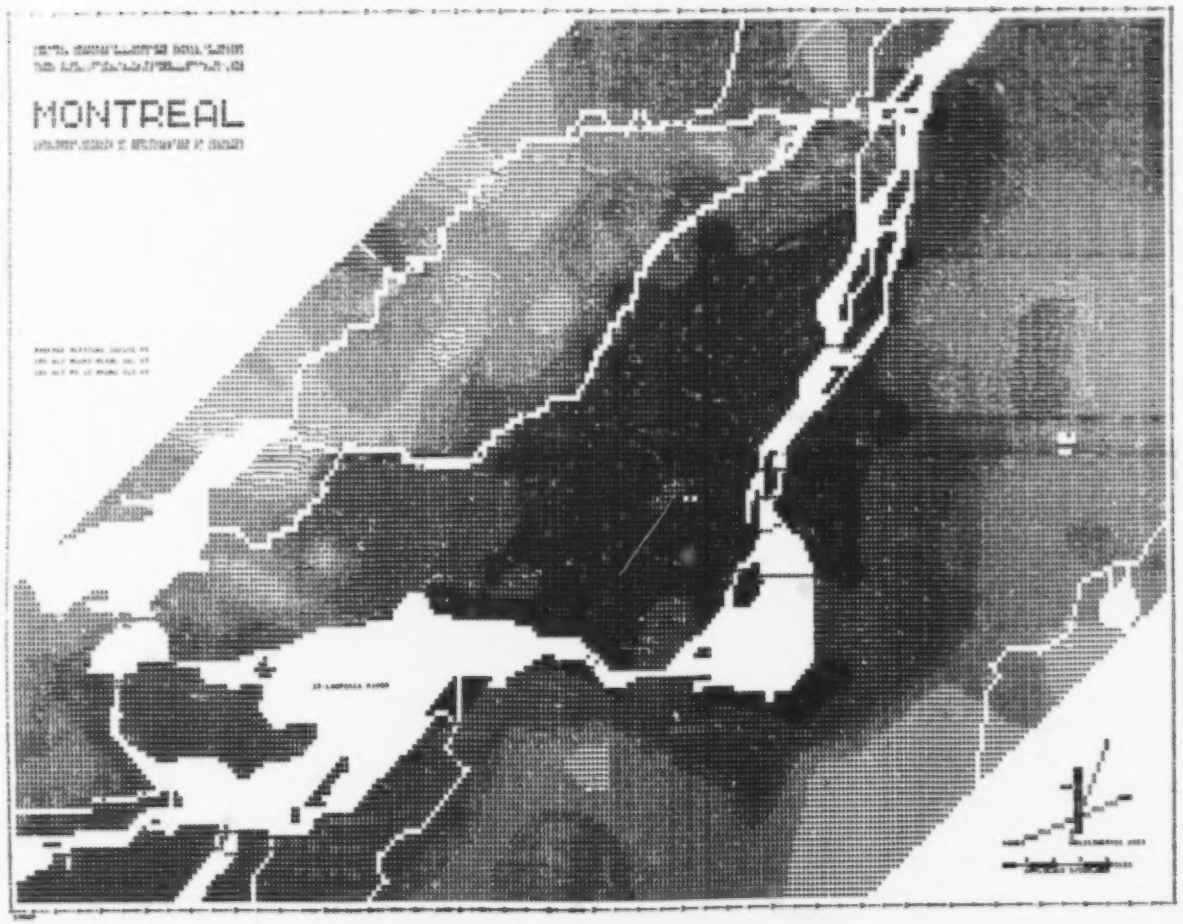

32

FIGURE E-2

MONTREAL REGION STUDY
Index of Atmospheric Purity
Equal Value Range

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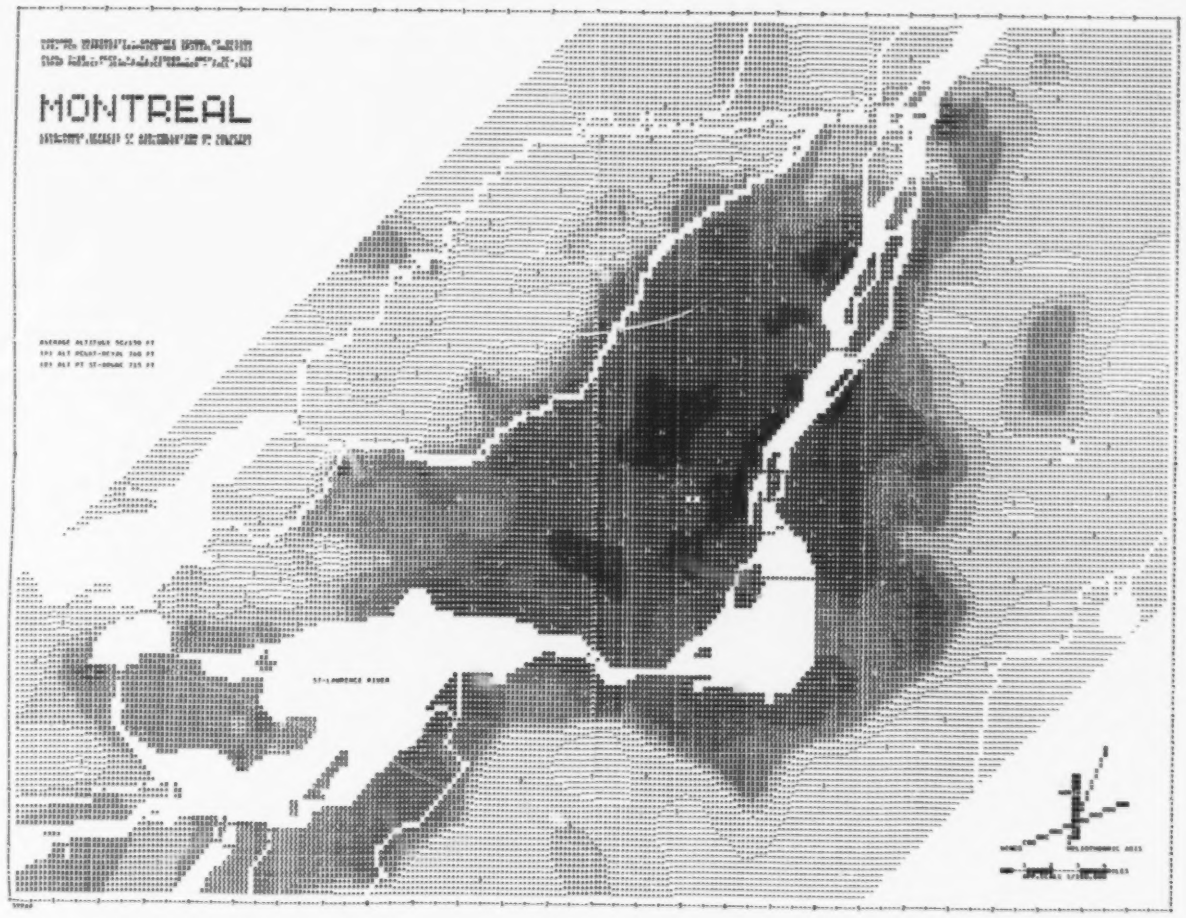

FIGURE E-3

MONTREAL REGION STUDY
Index of Atmospheric Purity
Equal Distribution of Data Points to Contour Levels

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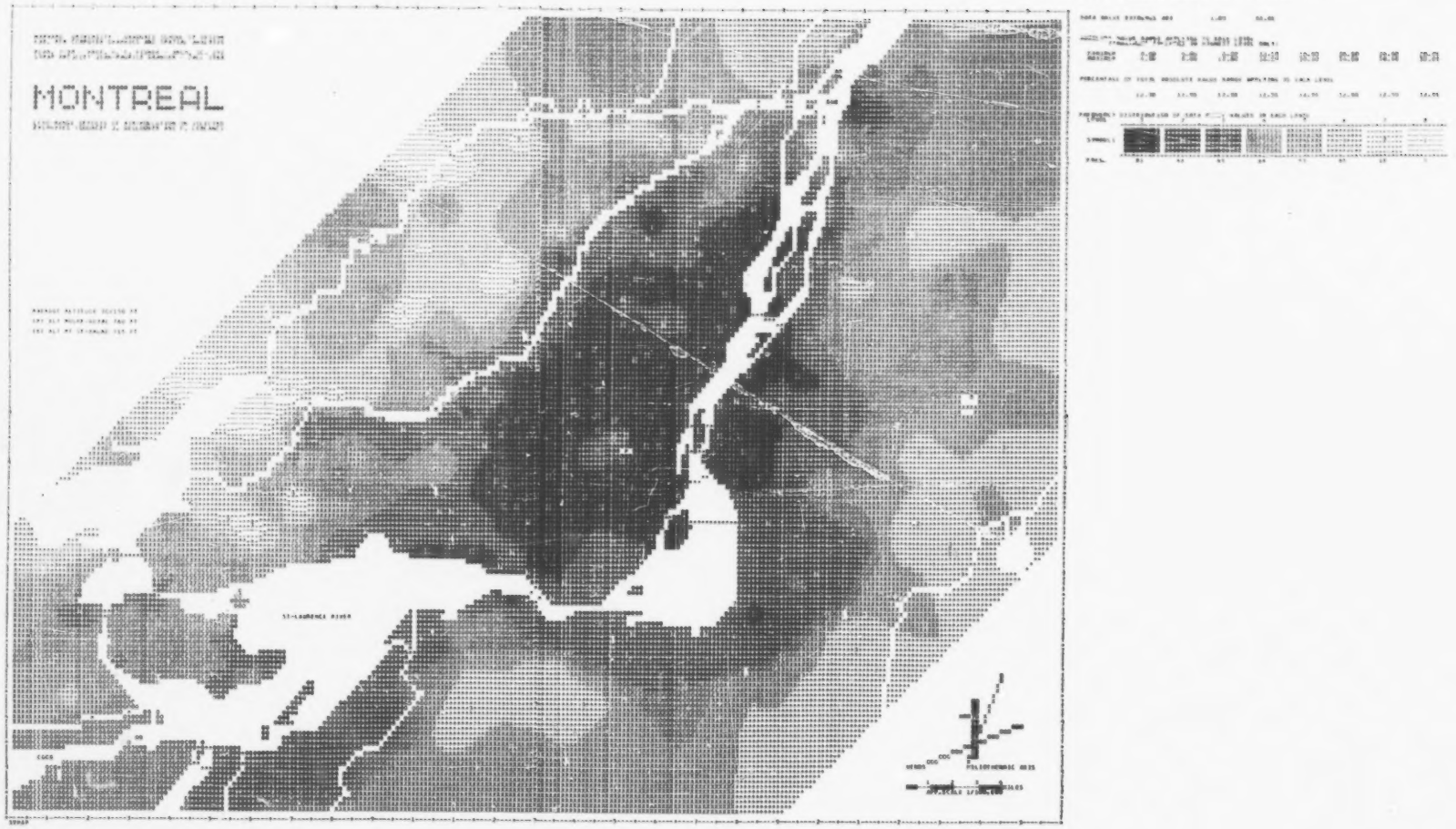

FIGURE E-4

MONTREAL REGION STUDY
Number of Epiphytes as an Air Pollution Index
Equal Value Range

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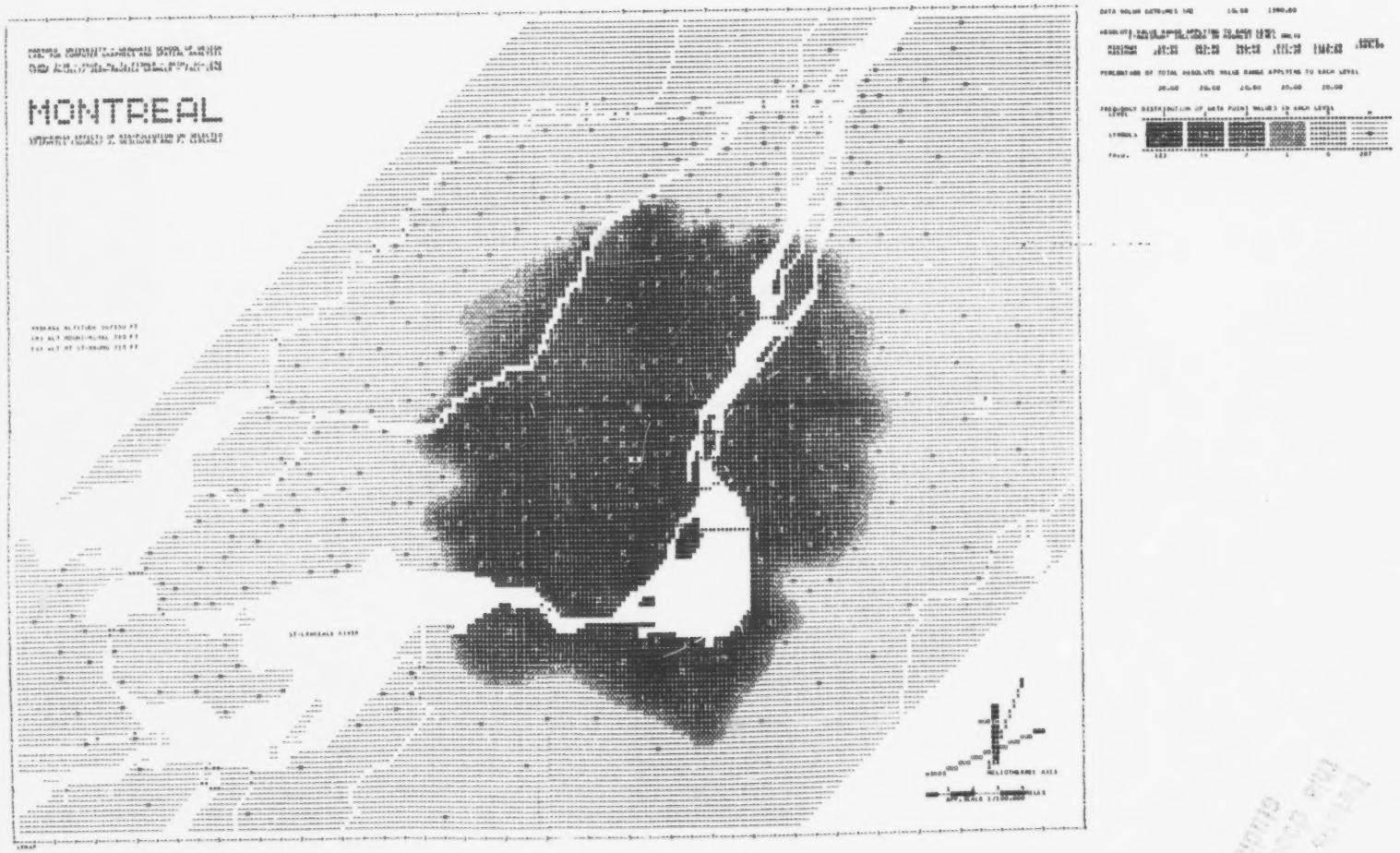

FIGURE E-5

MONTREAL REGION STUDY
Distribution of I. A. P. over the Urbanized Area
Equal Value Range

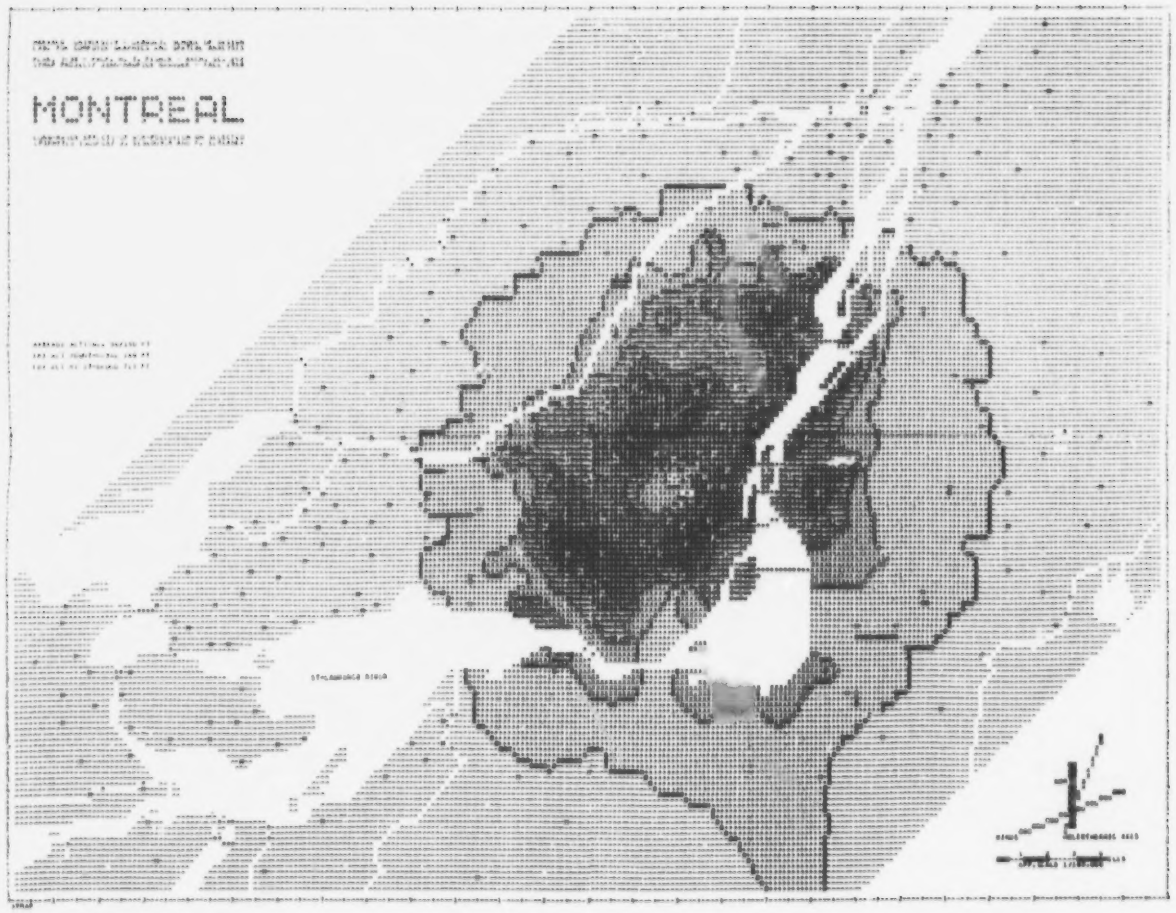

FIGURE E-6

MONTREAL REGION STUDY
Distribution of I.A.P. over the Urbanized Area
Equal Distribution of Data Points to Contour Lines

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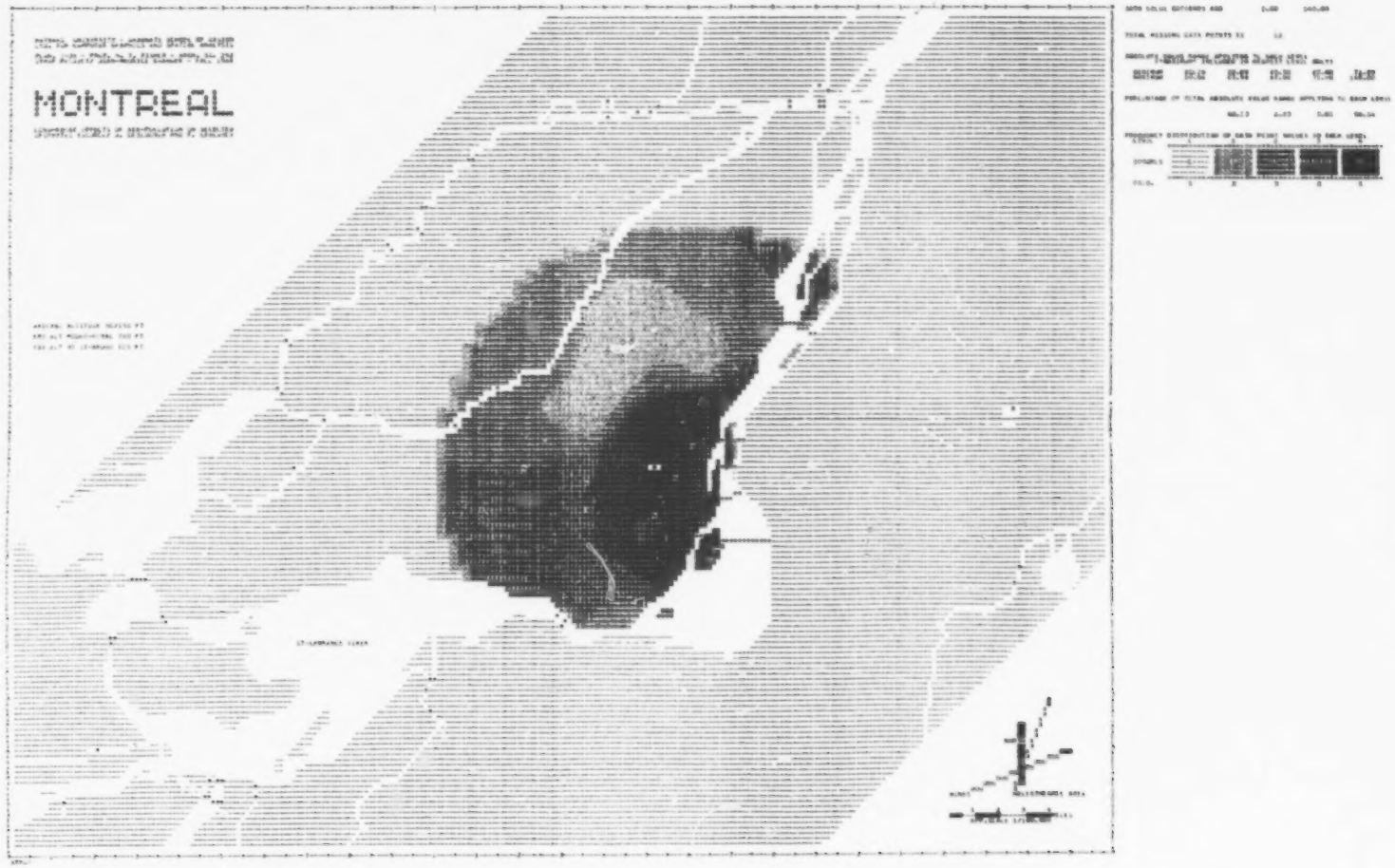

FIGURE E-7

MONTREAL REGION STUDY
Coefficient of Haze
City of Montreal Air Pollution Network

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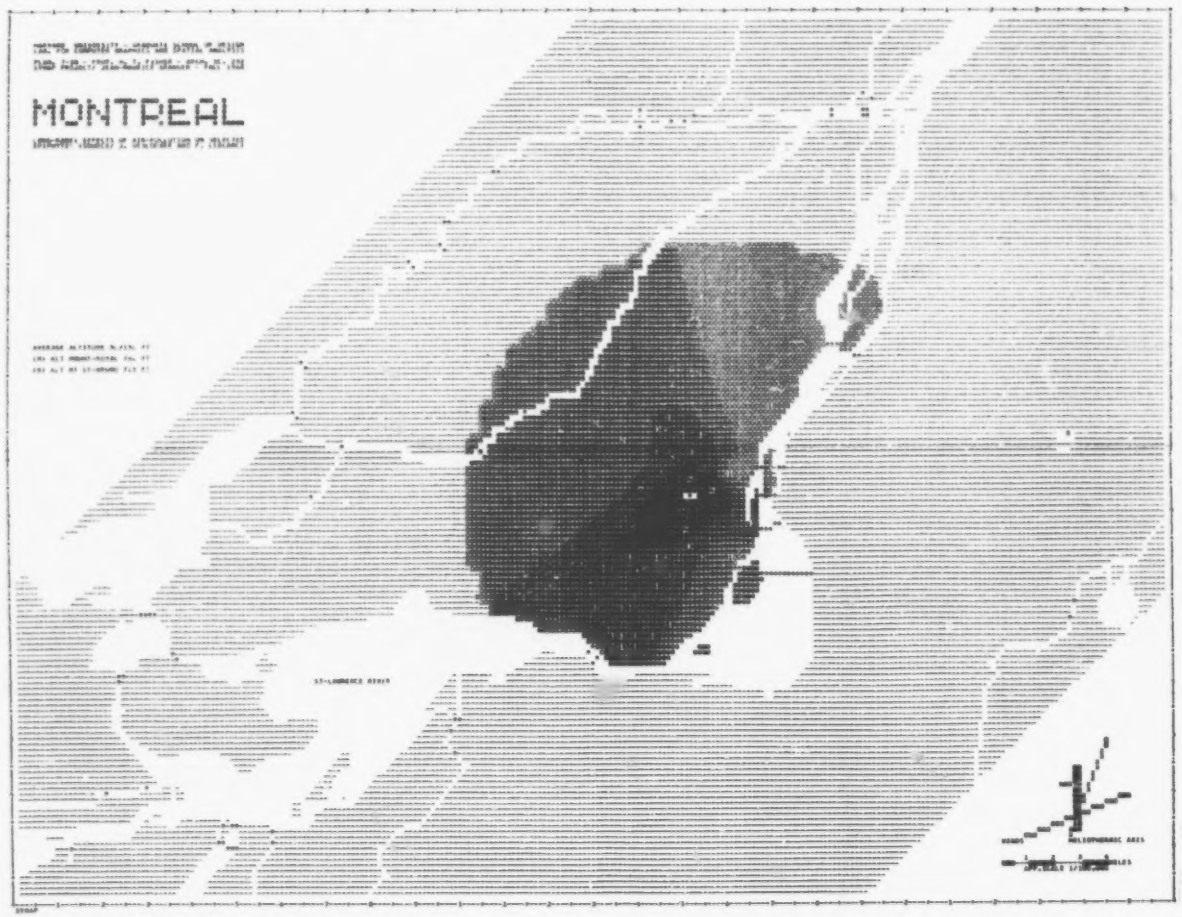

FIGURE E-8

MONTREAL REGION STUDY
Sulfur Dioxide
City of Montreal Air Pollution Network

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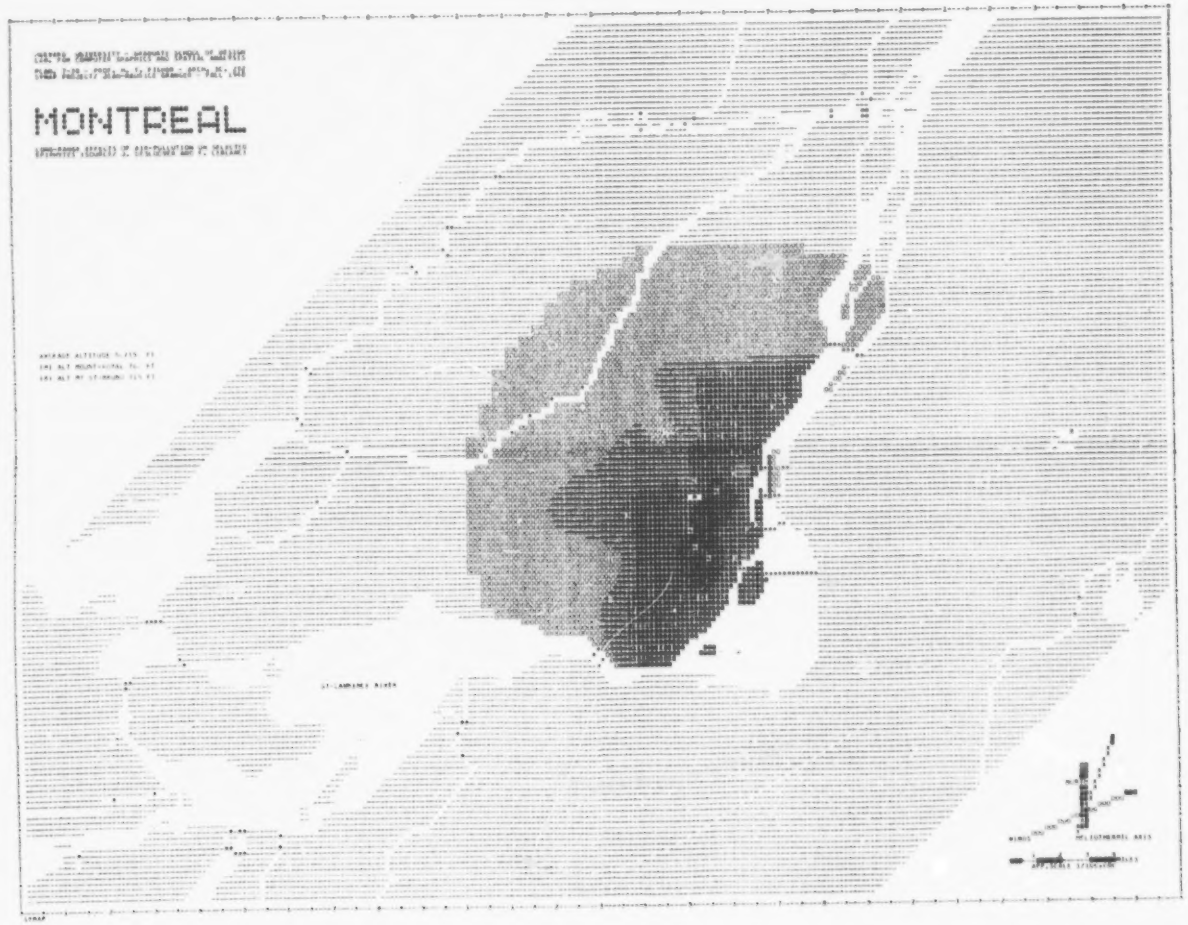
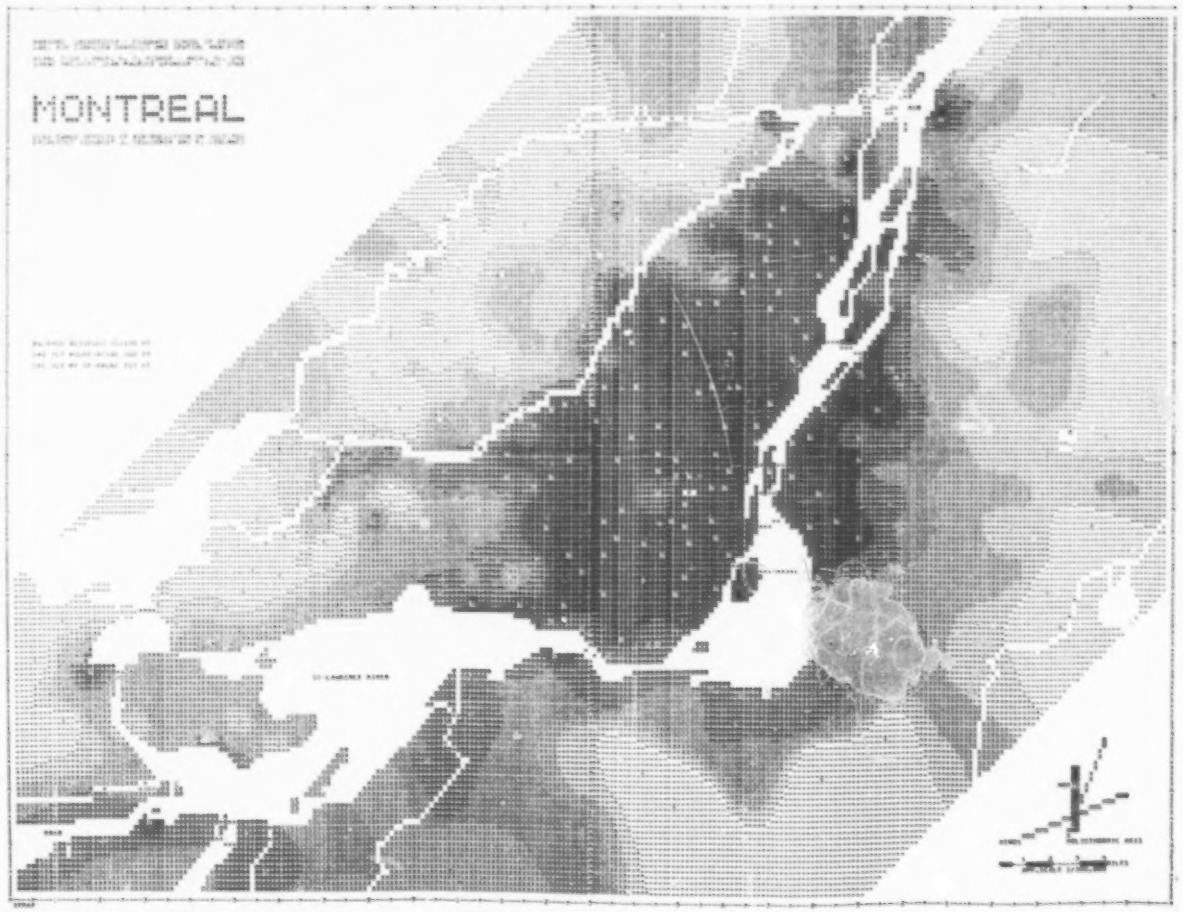


FIGURE E-9

MONTREAL REGION STUDY
Insoluble Residue
City of Montreal Air Pollution Network



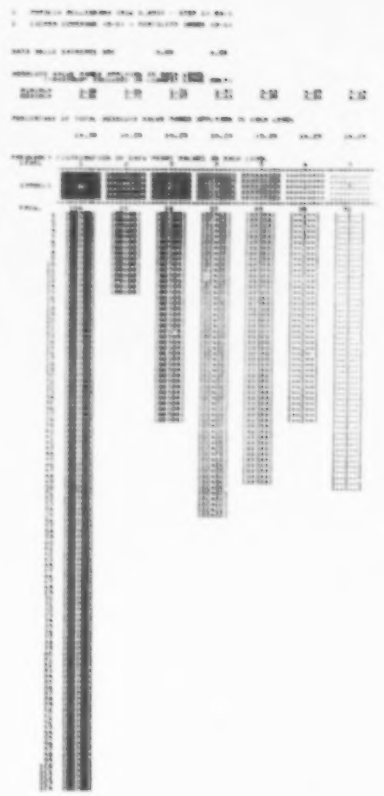
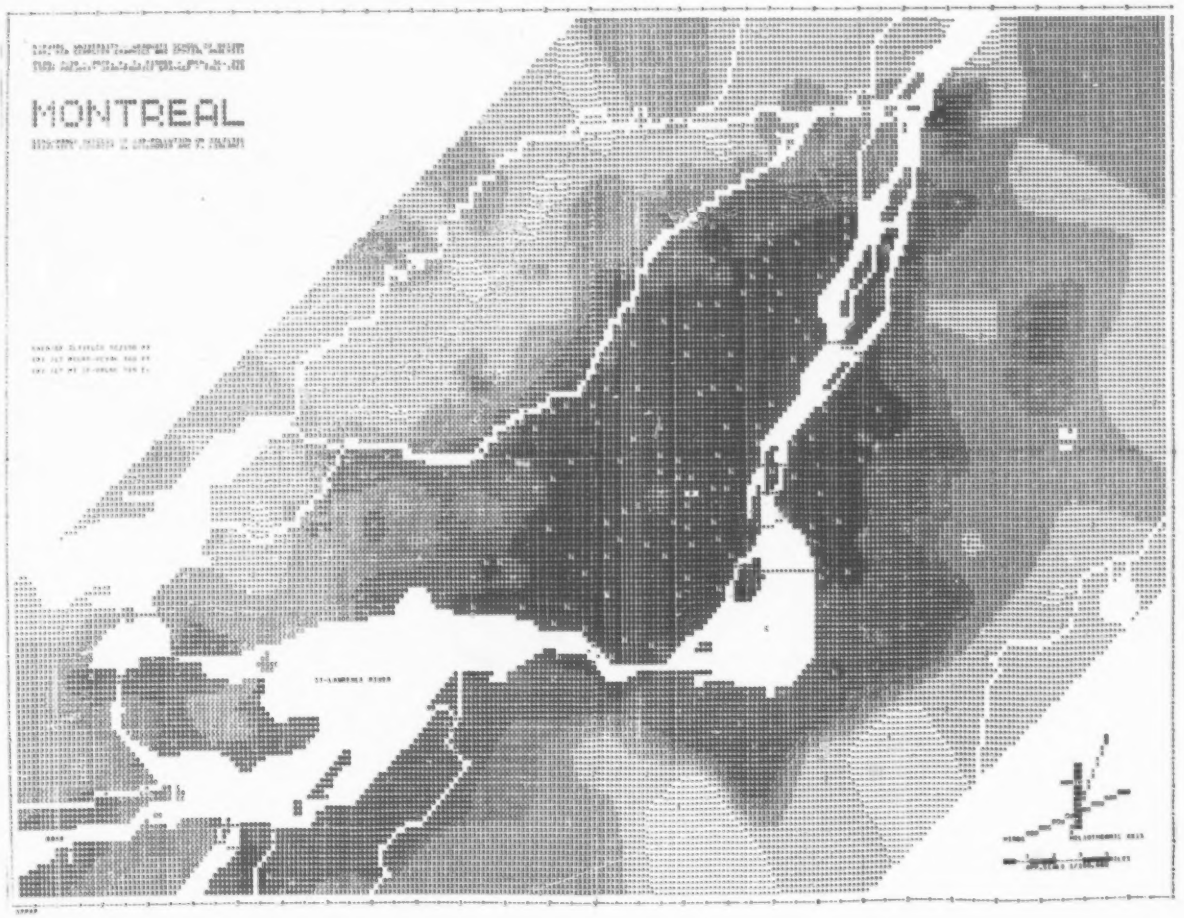


FIGURE E-10

MONTREAL REGION STUDY
"Best Selection" Procedure
Distribution of Physcia Millegrana by Coverage & Fertility

Details of illustrations in this document may be better studied on microfiche.



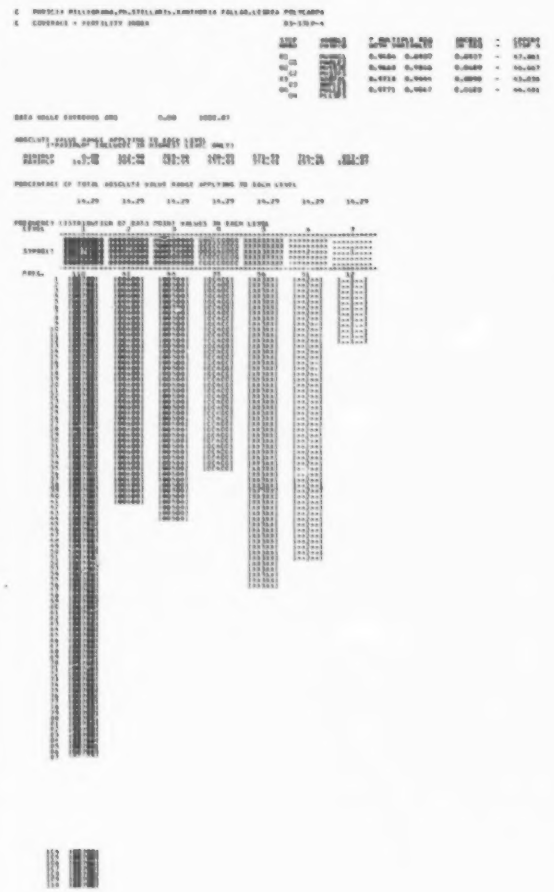


FIGURE E-11

MONTREAL REGION STUDY
"Best Selection" Procedure
Distribution of Physcia Millegrana, Physcia Stellaris,
Xanthoria Fallax, & Leskea Polycarpa by Coverage and Fertility

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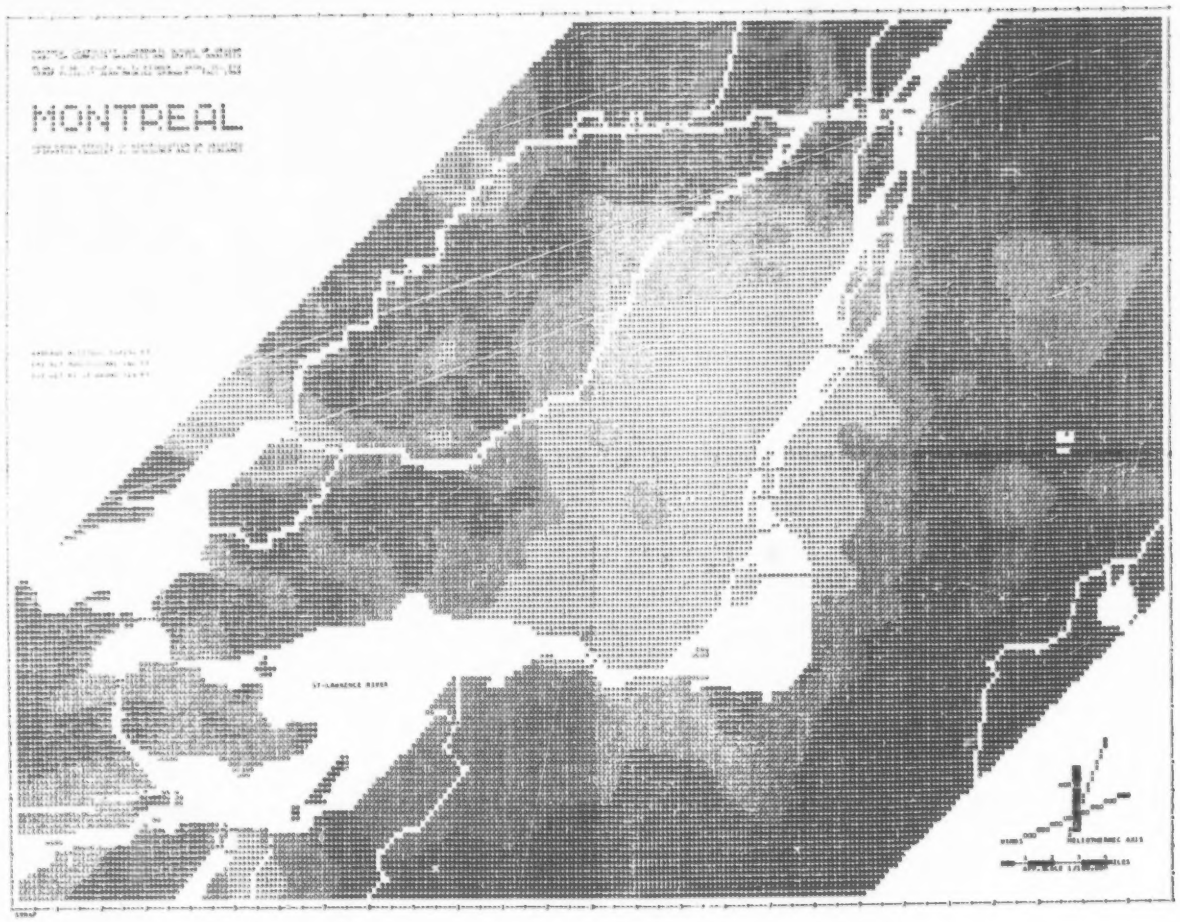

FIGURE E-12

MONTREAL REGION STUDY
Difference between Figures E-11 and E-2
Discrepancies in "Best Selection"

Details of illustrations in this document may be better studied on microfiche

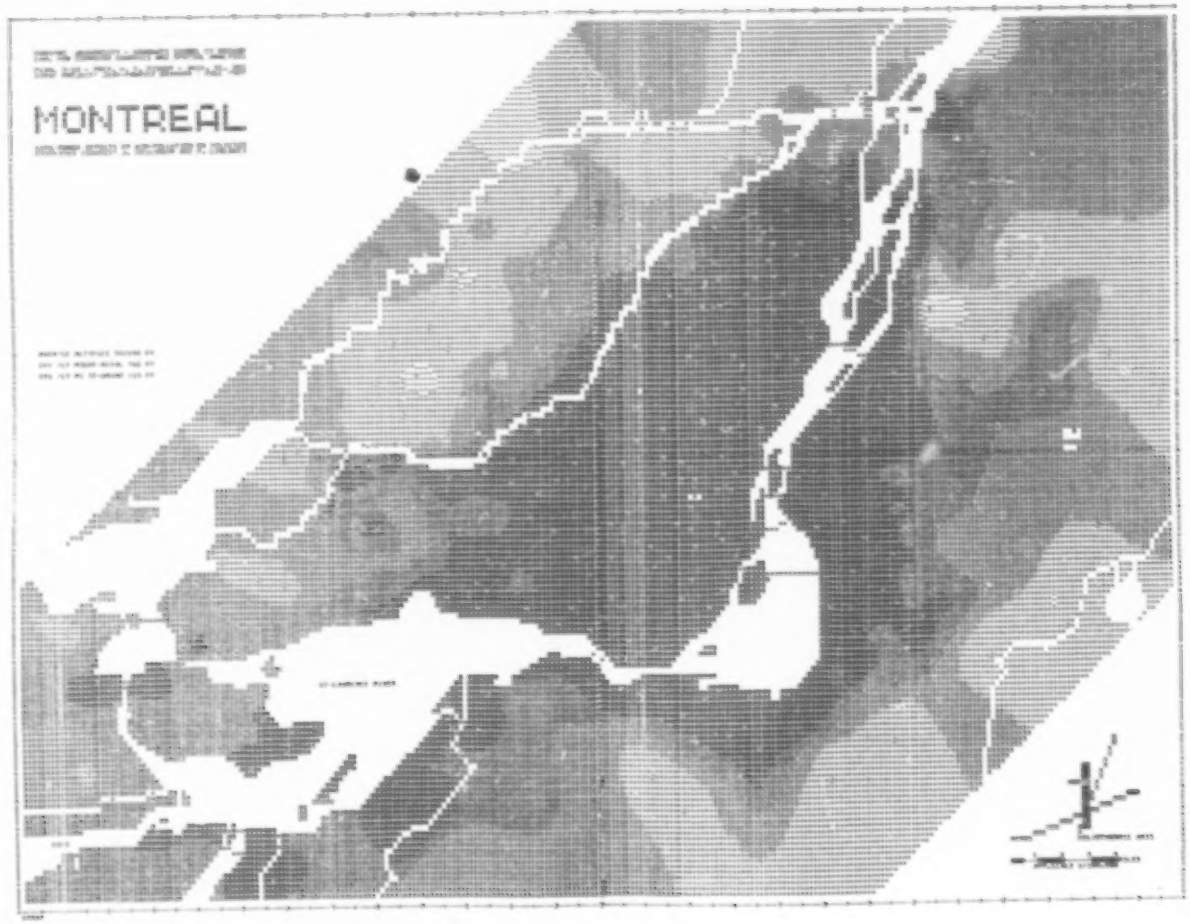

FIGURE E-13

MONTREAL REGION STUDY
"Alternate Selection" Procedure
Distribution of Physcia Millegrana, Physcia Adcendens,
Parmelia Subaurifera, & Xanthoria Fallax by Coverage only

Details of illustrations in this document may be better studied on microfiche

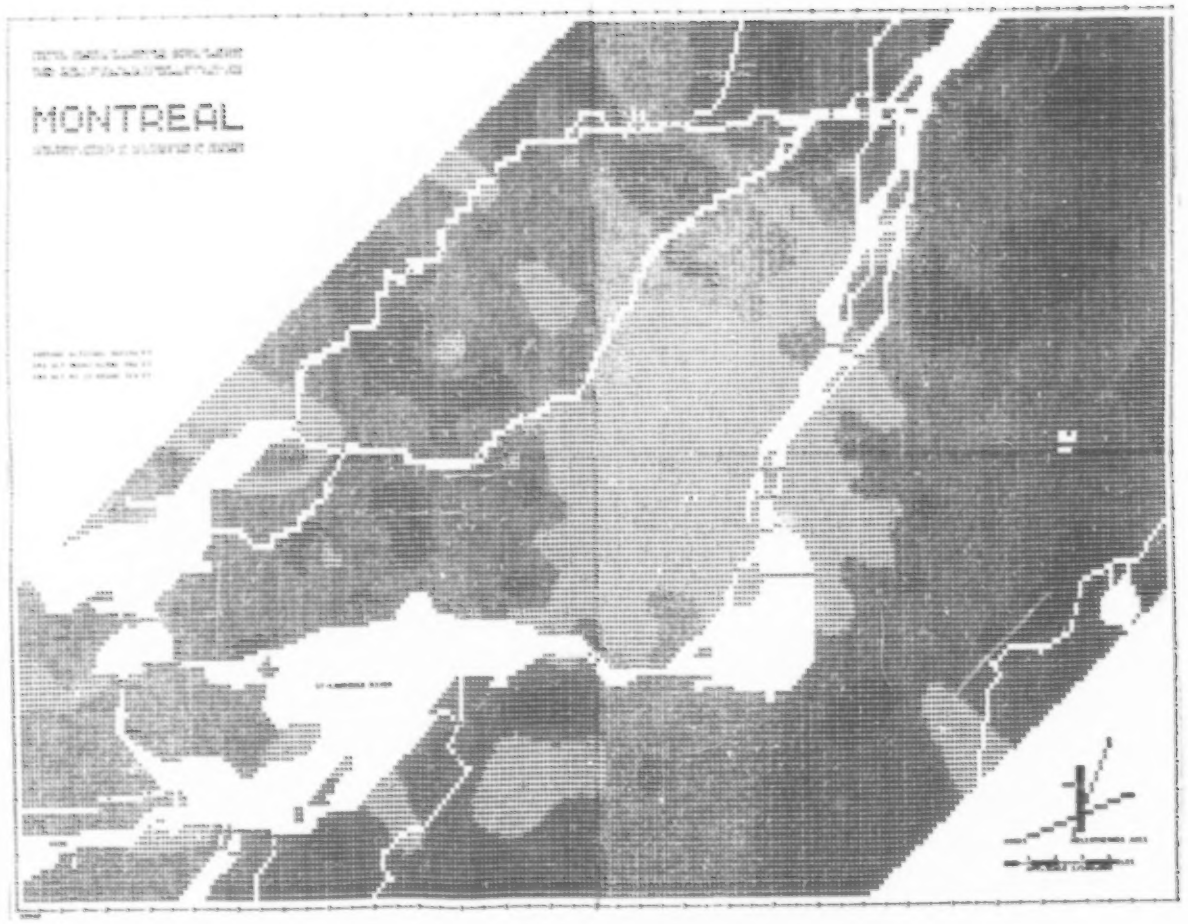

FIGURE E-14

MONTREAL REGION STUDY
Difference between Figures E-13 and E-2
Discrepancies in "Alternate Selection"

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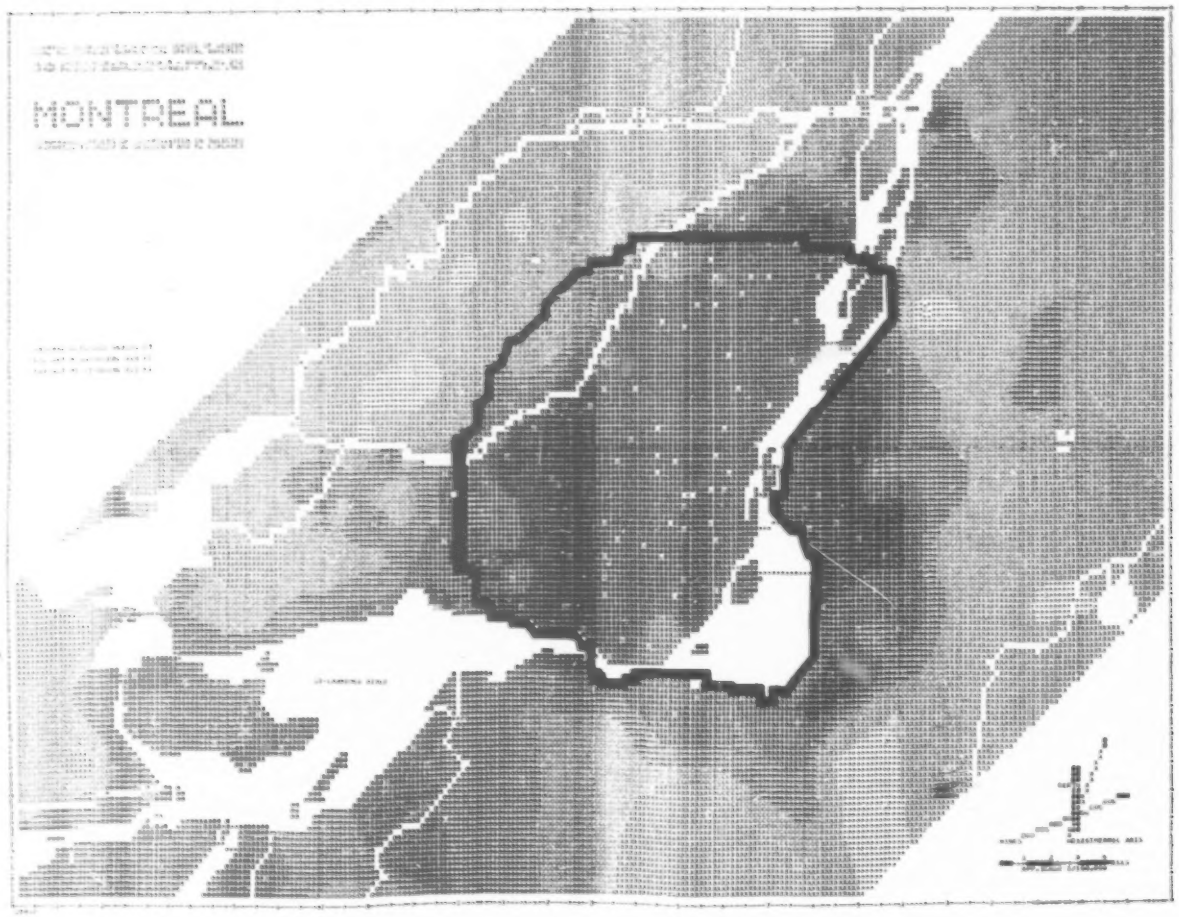

FIGURE E-15

MONTREAL REGION STUDY
"Alternate Selection" Procedure by Coverage
Composite of Separate Urban and Rural Mappings

Details of illustrations in
this document may be better

APPENDIX 2

SELECTED BIBLIOGRAPHY

1. Apparent Effect of Air-Pollution on the Distribution and Growth of Epiphytic Lichens and Mosses in Montreal, Fabius Leblanc, s.c. (Department of Biology, University of Ottawa, Canada) and Jacques DeSloover (Laboratoire d'Ecologie Vegetale, Universite de Louvain, Belgique) - 52 pages (including 7 maps) in a forthcoming publication of the Montreal City Planning Department, 1970.

   I Introduction; II The Environment: 1) Physical Characteristics 2) Climate 3) Industries; III Methods: 1) Location of Stations 2) Choice of Trees 3) Vegetation Analysis 4) Synthesis of the Data; IV Results: 1) Mapping 2) Frequency 3) Fertility 4) Coverage 5) Special Features; V Discussion: 1) Sensitivity of Plants to Air-Pollution, Especially SO_2; 2) Are Epiphytes More Sensitive Than Other Plants? 3) The Evils of Air-Pollution 4) The Situation in Montreal 5) Special Features of Mount Royal 6) The Future; VI Conclusion; VII References

2. Epiphytes and Air Pollution, Fabius Leblanc (Department of Biology, University of Ottawa, Canada) - 11 pages in "Proceedings of the First European Congress on the Influence of Air Pollution on Plants and Animals, Wageningen 1968," Centre for Agricultural Publishing and Documentation, Wageningen, The Netherlands, 1969.

   I Abstract; II Researches in the Wawa area; III Researches in the Sudbury area; IV Researches in the Montreal area; V Laboratory Experiments; VI Resume / Zusammenfassung; VII References.

3. Mapping of Atmospheric Pollution on the Basis of Lichen Sensitivity, Jacques DeSloover and Fabius Leblanc, s.c. - 15 pages in "Proceedings of the Symposium on Recent Advanced Tropical Ecology," R. Misra and B. Gopal, ed., 1968, The International Society for Tropical Ecology.

   I Introduction; II Detection of Atmospheric Pollution by its Effects on Epiphytes: 1) Prerequisites (choice of substratum; choice of the stations; phytosociological considerations;

presentation and interpretation of data) 2) Historical Background (species distributive maps; vegetational maps) 3) The Proposed Method (choice of stations and phorophytes; phytosociology; degrees of toxiphoby; index of atmospheric purity; synthesis of the data; applications) III Conclusions; IV References; V Discussion.

4. Influence of an Iron-Sintering Plant on Corticulous Epiphytes in Wawa, Ontario, D. N. Rao and Fabius Leblanc, s. c. - 17 pages in "The Bryologist," vol. 70, no. 2, Summer 1967.

I Abstract; II Introduction; III Materials and Methods; IV Results; V Discussion: 1) Dispersion of Pollutants 2) Topographic Features, Fog, Humidity, Temperature and Light Intensity 3) Fallout of Sulphur Dioxide and its Effects on Water, Soil and Vegetation 4) Terricolous Mosses and Lichens and their Tolerance to Pollution 5) Epiphytes as Indicators of Atmospheric Pollution; VI Literature Cited.